AD NUMBER
ADB008881
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 07 NOV 1975. Other requests shall be referred to ADC/DEECE, Ent AFB, CO 80912.**
AUTHORITY
AFGL ltr, 6 Nov 1981

THIS REPORT HAS BEEN DELIMITED AND CLEARED FOR PUBLIC RELEASE UNDER DOD DIRECTIVE 5200.20 AND NO RESTRICTIONS ARE IMPOSED UPON ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

AD B008881

AFCRL-TR-75-0576

AIR FORCE SURVEYS IN GEOPHYSICS, NO. 331

Richmond Air Force Station Strong Motion Study-Preliminary Report

HENRY A. OSSING
FRANCIS A. CROWLEY

7 November 1975

Distribution limited to U.S. Government agencies only; (Test and Evaluation ~~of Military Systems/Equipment~~); (7 November 1975). Other requests for this document must be referred to ADC/DEECE, Ent Air Force Base, Colorado 80912

TERRESTRIAL SCIENCES LABORATORY PROJECT 7628

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

Qualified requestors may obtain additional copies from the Defense Documentation Center.

AF CRL –

14 AFSG – 331,

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AFCRL-TR-75-0576	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 RICHMOND AIR FORCE STATION STRONG MOTION STUDY – PRELIMINARY REPORT.		5. TYPE OF REPORT & PERIOD COVERED: Scientific. Interim.
		6. PERFORMING ORG. REPORT NUMBER: AFSG. No. 331
7. AUTHOR(s): 10 Henry A. Ossing, Francis A. Crowley		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts 01731 — 16 AF-7628		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62101F 76280902 — 17
11. CONTROLLING OFFICE NAME AND ADDRESS: ADC/DEECE, Ent AFB, CO 80912 — 12 26p.		12. REPORT DATE: 11 7 Nov[redacted]75
		13. NUMBER OF PAGES: 29
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U. S. Government agencies only; (Test and Evaluation ~~of Military Systems/Equipment~~); (7 November 1975). Other requests for this document must be referred to ADC/DEECE, Ent Air Force Base, Colorado 80912

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

9 Air Force surveys in geophysics,

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Vibration effects
Quarry blasting
Strong-ground motion
Seismic instrumentation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The implementation of a strong-ground motion study at Richmond AFS is presented. The study was necessitated by suspect effects of near quarry operations on station facilities. Geologic and predicted velocity profiles are presented together with charge-weight, scaled distance determinations. The data acquisition system known as the Seismic Activity Monitoring System (SAMS), employed at the Richmond site, is described in detail.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

011 800

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Contents

Illustrations

Illustrations

Tables

Richmond Air Force Station Strong Motion Study—Preliminary Report

1. INTRODUCTION

A study of strong motion effects, that is, vibratory motion induced by local quarry operations, is being conducted at Richmond Air Force Station, Richmond Heights, Florida. Richmond AFS occupies a three-acre section of the northwest corner of the inactive Richmond Naval Air Station and contains elements of both the Air Force, Army, and FAA. Approximately fifteen small one-story buildings and antenna towers are located on the site which serves as the Headquarters for the ADC 644th Radar Squadron. Located due north of the station is a limestone quarry operated by the Sterling Stone Crushing Company whose southern boundary is approximately 1200 ft from the Richmond AFS. Up until 1972 the quarry operating activity was centered 4200 ft, more or less, from the Richmond AFS main search radar antennas.[1] Since then the operation has shifted south so that quarrying activity occasionally occurs 1200 to 1400 ft from the Richmond facilities.

Prior to 1972 the quarry blasting was of a sufficient audio level to be of significant nuisance to station personnel, while coincidentally a degree of building damage, to the extent of falling masonry, was observed. It is to be noted that this damage was not shown to be related directly to ground motion effects due to

(Received for publication 7 November 1975)

1. Lt Col Oaks, M., Ltr 6 Dec 1971, Subject Blast Damage to Government Property.

the quarry activities.[1,2] Air Force remedial action prior to 1972 was a meeting with the officials of the quarry who, in turn, agreed to reduce the number of shot holes and to modify the time delays used with multiple hole detonations. However, with the shifting of the quarry activity to the more proximate southerly location, deep concern arose not only with reference to the structural damage potential, but also to major alignment deviations of both the main search radar as well as to the two AN/FPS-6 Height Finders.[1]

ADC approached AFCRL to conduct a motion survey for determining the ground-motion levels at the Richmond Air Force Station due to the quarry activity. In particular, a determination should be made as to whether the quarry is operated in accordance with the regulations specified in the Dade County Code on Explosives, as referenced in Chapter 13, Section 13-12.[3] This section specifies the restraints to explosive generated motion in terms of both amplitude and particle velocity. Based on the foregoing, AFCRL fabricated a Seismic Activity Monitor (SAM) specifically designed to acquire strong motion seismic data predicated on a threshold level exceedance. This paper describes AFCRL's approach to instrumenting and conducting this ground-motion study, now in progress at Richmond Air Force Station.

2. SITE DESCRIPTION

The Richmond Air Force Station services the ADC 644th Radar Squadron, US Army, Air Defense Command, and the FAA. The FAA owns and maintains the primary search radar that is used by both the Air Force and the Army for all air route traffic coming into southern Florida. This radar facility is the primary surveillance and air traffic control for this area. In addition to the search radar, two Air Force AN/FPS-6 height finder radar antennas operate within 600 ft of the search radar, Figure 1. Between the search radar and the height finders are the operations building, (Bldg 060), the communications-electronics building (Bldg 070), and the FAA building. The radar signals from the FAA search radar and the Air Force height finders are cabled to these three one-story buildings via underground conduits. Of concern is that buildings 060 and 070 have suffered some structural damage in the form of major cracking of ceilings, interior and exterior walls, while building 070, in addition to the cracking, has had six concrete building blocks fall from the building's northwest corner.[1] Both the

---

2. EN-DI Disposition Form, 3 March 1972, Subject: Blasting Effects at Richmond Air Force Station, Florida.
3. Dade County Code on Explosives (1973), Dade County, Florida.

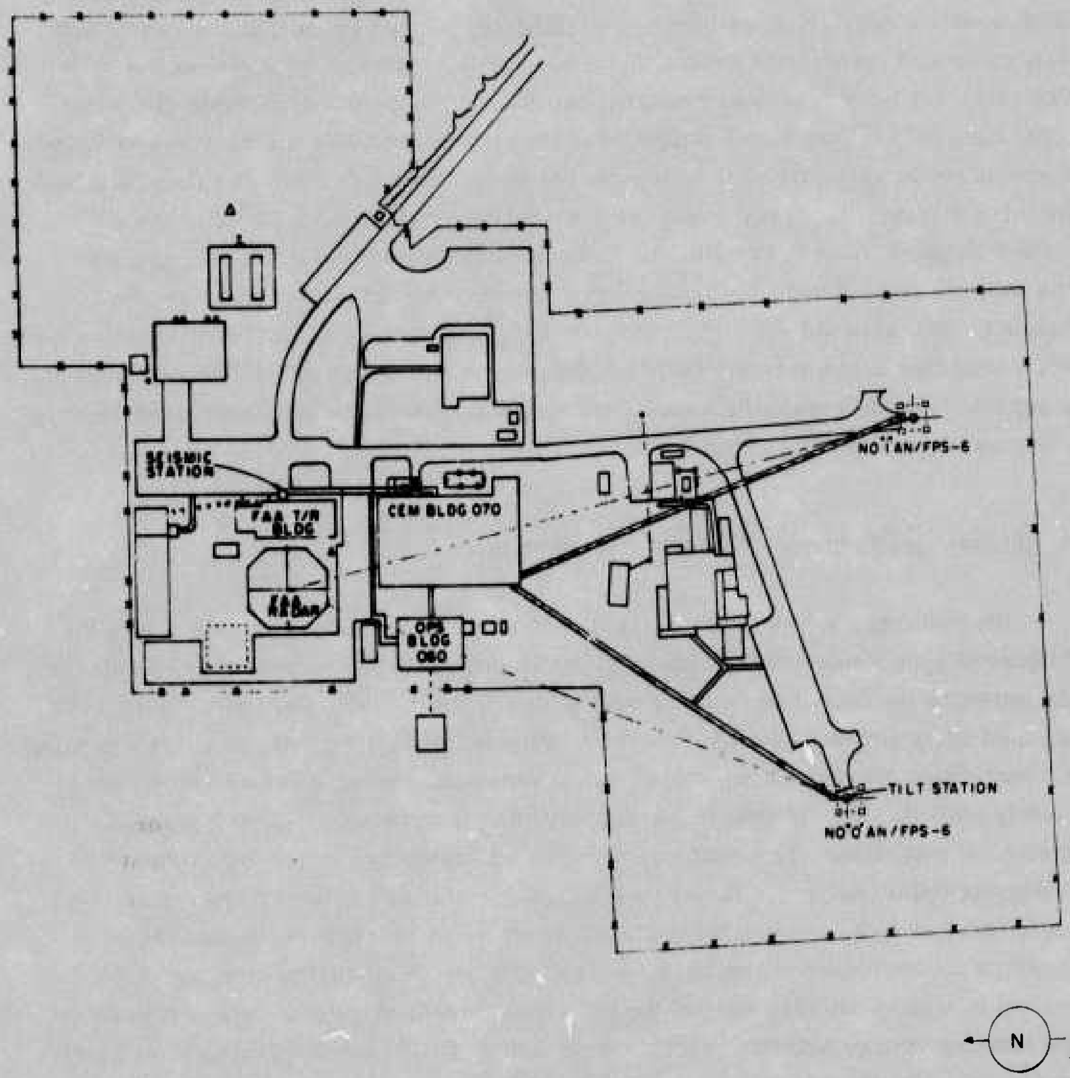

Figure 1. Map of Richmond Air Force Station

search radar and the height finders operate under stringent alignment tolerances. The search radar cannot operationally tolerate deviations of 2 mils while the height finder operational tolerance is 0.4 mils. The concern here is that if these tolerances are exceeded it will take the better part of one week to effect equipment realignment and one week to flight check it.[4]

4. Minutes of ADC Meeting Concerning Sterling Stone Crushing Co., 17 Dec 1971.

AFCRL Seismic Activity Monitoring System (SAMS) was installed at the Richmond station during the week of 23 June 1975. The reason for the inordinate delay was that the quarry ceased operation for the better part of a year due to the downturn in economy on the construction industry, and did not resume operation until June 1975. One three-component seismic station, monitoring three orthogonal components of earth motion, was installed within the cable conduit east of the FAA building (Figure 1). A two-component earth-tilt station was located in the AN/FPS-6 Height-Finder tower No. 0. Data lines were laid underground from both the seismic and tilt stations to building 070 where the SAM recording station is located. The seismic data are presently being recorded digitally on magnetic tape via a modified magnetic tape buffer recorder while tilt data are being recorded on a separate analog recording unit. Description of the component instrumentation is contained in a following section.

3. QUARRY OPERATION – BLASTING PARAMETERS

The Sterling Crushed Stone Company has conducted quarry operations in the Richmond area since 1957.[4] Blasting activity up to 1972 has been concentrated in the northern portion of the quarry over 4,000 ft from Richmond AFS. Since 1972 the quarrying activity has been moved to the southern portion of the quarry forming a water-filled pit measuring some 50 ft in depth and having a diameter of approximately 2000 ft. The southernmost limit of the pit approaches 1200 ft from the Richmond facilities. The rock quarrying is accomplished in a counterclockwise expanding spiral pattern. Hence, periodically the blasting source will approach the Richmond AFS in a southerly direction while the blasting occurs on the quarry's western face. The blasting itself attains its closest proximity to the station at a point slightly east of the pit's most southern extremity at which point the blasting source activity retreats to the north while quarrying the eastern face of the pit. The time it takes to complete one circuit under normal conditions is three to four months. However, recently the activity has been vacillating due to economic fluctuations in the construction field thus affecting the above mentioned time frame.

Quarrying procedures employed by the Sterling Crushed Stone Company have been documented in references 1 and 5. Summarizing, for one blasting sequence 8 to 20 shot holes are drilled via a special drilling rig used for drilling 50 ft holes, the charge depth. Usually one time delay fuse of 25 msec is used for each hole. Occasionally fuses of 250-msec delay were used in the past. The 25-msec

5. Keith, J., Ltr 11 Feb 1972, Subject: Consultation Concerning Blasting Effects at Richmond Air Force Station, Florida.

time-delay fuse was chosen to conform with the recent theory that displacement amplitudes, due to ripple firing having between 9 to 30 msec delays, are reduced compared with those ripple firings having time delays outside these limits. However, one hole per time delay is not singular to this quarry operation as company officials have admitted to using two holes per time delay interval.[2] Reportedly, the standard charge weight used by the quarry is 165 lb per hole but should one time-delay fuse per two holes be used, the charge weight then is effectively doubled, that is, 330 lb.

To gain some perspective of the charge weight prerequisites necessary for potential structural damage, the following exemplifier serves, in a very general manner, to illustrate the charge weight distance relationship predicated on the conditions prevailing at Richmond. A number of scaled distance formulations, all based upon blasting data extrapolated from a limited sample of individually restrictive quarry sources, have been developed in recent years. One of these equations, reported to be founded on "the most complete data",[6] provides a relationship between the maximum allowable charge weight and source distance. Using this empirical relationship

$$W^{2/3}/D = 0.08,$$

where W is the charge weight (lb) and D is the distance from the source (ft), a graph was made, based on the single hole charge weight information said to be used by the Sterling Stone Crushing Company, to determine the minimum safe distance from the source for a given charge weight. As can be determined from Figure 2, if one time delay is used for one hole containing a charge weight of 165 lb and for two holes having a total charge weight of 330 lb, the minimum safe distance would be 380 and 610 ft, respectively. Accordingly, three, four, and five holes per one time delay would have minimum safe distances of 800, 975, and 1125 ft from the source, again assuming only one charge per hole of 165 lb. The closest shot distance to the Richmond AFS is 1200 ft, hence, a maximum allowable charge weight in excess of 900 lb per delay interval would be required for the facility to suffer damage using the above equation. If the damage to the Richmond AFS buildings is indeed due to the quarry operation, then this would imply that the quarry operators are exceeding their normal charge weight per delay by a factor of six. Emphasis is made that the criteria used here are only general and does not take into consideration site constants due to local geological conditions which are not provided for by the formulation. Although some insight can be gained by

---

6. Harris, C., and Creed, C. (1961) Shock and Vibration Handbook, Vol 3, McGraw-Hill Co., New York.

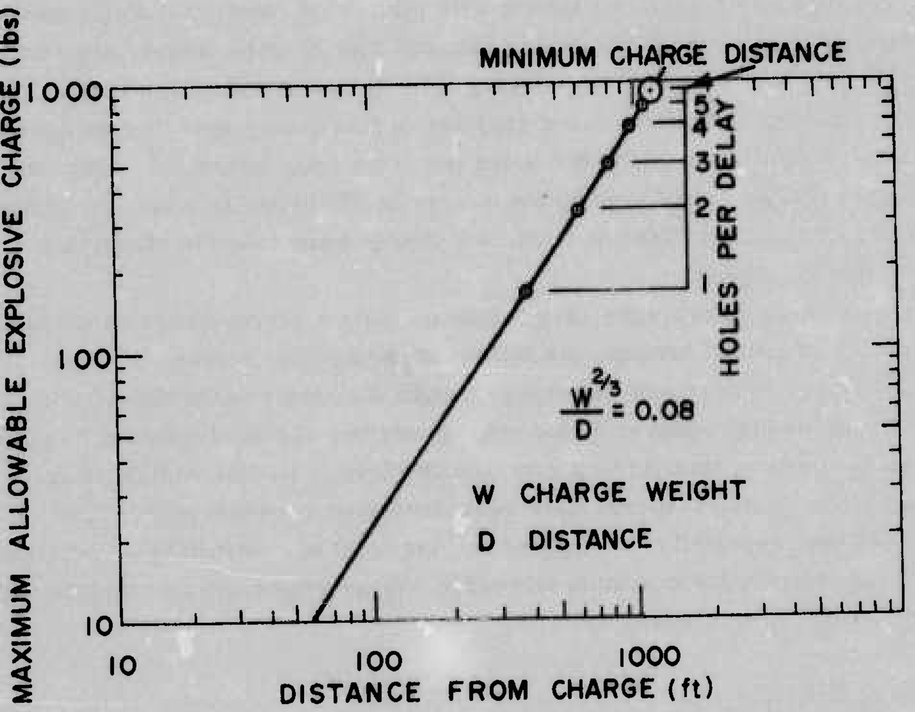

Figure 2. Explosive Charge Weight vs Distance

considering the relationship between distance and charge quantity, those parameters, however, governing the judicable aspects are quite different.

Blasting, related to quarry operations in Dade County, Florida is regulated under Chapter 13, Dade County Code on Explosives.[3] Standards set for quarry operations recognize that any blasting operation resulting in a particle velocity of more than 2.0 in./sec could cause structural damage. More explicitly, the code declares it unlawful for a blast that results in a component vector sum particle velocity in excess of 1.0 in./sec or a displacement (amplitude) component vector sum in excess of 0.03 in. when measured proximate to the nearest building, not owned by the user, located within one statute mile of the blast source. Further the quarry operator must at all times maintain a "continuous monitoring seismic instrument" at each active site. This instrument must be calibrated annually and certified.

The code also requires the user to maintain daily records of all blasting activity up to three years. These records require documentation as to site location, date and firing time, charge spacing, explosive quantity for each time-delay series, time-delay interval, blasting permit number, individuals in charge of loading and firing, and the name of the reporting individual. By law an independent seismologist or vibration engineer will analyze the blast data on a monthly basis. Hence, documentation compiled by the user for a given blast or blasting sequence, should be publically available for comparison purposes with those data collected independently by a second party acting within the statutes prescribed by the Dade County Code on Explosives.

4. RICHMOND AREA STRATIGRAPHY

The geological stratigraphy of the Florida plateau is limestone rock overlying mica-shale paleozoic rock. On evidence based primarily on well logging, major deformations occurred in the Florida area prior to the Pleistocene (glacial) Epoch as subsequent bedding planes are all horizontal. The area of the Florida plateau occupied by Dade County, of which Richmond is a part, has three distinct topographical features: coastal lowlands to the east, the Everglades to the west, and the two separated, more or less, by a topographic anomaly of sorts known as the Atlantic Coastal Ridge. Richmond Air Force Station is located on this pseudo ridge. The Atlantic Coastal Ridge is no more than 50 ft at its highest elevation above sea level although most of it is considerably less. It has a rock foundation, the first layer of which is the ubiquitous Miami Oölite formation. Miami Oölite is a soft, white oölithic limestone up to 30 ft in thickness near the coast gradually decreasing in thickness to the west. It was sedimentarily deposited between glacial ages (Sangamon) during the Pleistocene Epoch. This rock presently is heavily quarried for building stone and road metal purposes. Shallow Pamalico terrace sands (0 to 2 ft thickness) lie unconformally over the Miami Oölite along the length of the Atlantic Coastal Ridge. These terrace sands were deposited during the late Pleistocene and were directly formed due to the extensive glacial recession in the more northerly portion of the continent.[7,8]

Stratigraphically, the rock formations below the Miami Oölite, beginning with the Tamiami formation, extend to at least 3000 ft in the Atlantic Coastal Ridge area. They are consistent in that they are all of soft-medium limestone differing only in color and oölithic composition save for the bottom-most formation, the Cedar Keys formation, deposited during the Paleocene Epoch, which is a hard limestone varying some 3000 to 5000 ft below sea level. Identifiable named formations between the Tamiami and Cedar Keys formations are, at increasing depth, the Hawthorne, Lake City, and Oldsmar formations. Each of these

---

7. Parker, G., and Cook, W. (1944) Late Cenozoic Geology of Southern Florida with a Discussion of the Ground Water, Geological Bull. No. 27, Florida Geological Survey.

8. Cook, W., (1945) Geology of Florida, Geological Bull. No. 29, Florida Geological Survey.

formations lies conjointly unconformally with the formation below.[9] Stratigraphical information below 5000 ft is not available for this area.

5. ESTIMATED SEISMIC VELOCITY PROFILE

An estimate of the seismic velocities peculiar to the Richmond area was formed predicated on (1) the stratigraphy and physical characteristics of the known geologic formations underlying the area,[8,9] and (2) the seismic velocities of representative rock types established under experimental conditions.[10] Based on this information, velocity parameters were used to calculate a Rayleigh wave dispersion curve best fitted to model sets previously formulated.[11] The case model chosen was a single layer over a half-space. The reason for this selection was that the rock formations within the first 3000 ft are of the same generic type, that is, soft limestone differing basically only in calcareous composition and color. Thus the seismic wave propagational qualities for the sundry formations should not vary significantly from one formation to the next. Hard limestone formations are first mentioned at depths of 3000 to 5000 ft.[9] Therefore, the average depth of 4000 ft was arbitrarily picked as the single layer, half-space boundary. The phase (C) and group velocity (U) curves (Figure 3) are a fraction of the figurative velocity profile depicted in the figure's lower right hand corner. The compressional-shear velocity ratios given, as representative of the Richmond area, are a close approximation to the velocity ratios used in the model computation. This approximation was the basis for selecting the model used (Case SL 4474) as being representative.[11] Of note is that, if indeed this case model serves as a good approximation of the velocity and dispersive properties for the Richmond area, then air-coupled effects should be quite negligible since the shear velocity, β_1, of the single layer, the determining factor for air-coupled waves, is much greater than the compressional velocity in air, α_0.[12] Hence, air to ground constructive wave interference should not be expected. Further, from the model the slowest velocity surface wave one might expect is in the neighborhood of 3.0 sec, but the wavelengths for these waves are much greater than the relatively short

---

9. Puri, H., and Vernon, R. (1964) Summary of the Geology of Florida and a Guidebook to the Classic Exposures, Special Publication No. 5, Florida Geological Survey.

10. Clark, S. (1966) Handbook of Physical Constants, Geological Society of America, New York.

11. Mooney, H., and Bolt, B. (1965) Dispersion Tables for Rayleigh Waves on a Single Surface Layer, VESIAC Special Report 4410-102-X.

12. Ewing, W., Jardetzky, W., and Press, F. (1957) Elastic Waves in a Layered Media, McGraw-Hill Co., New York.

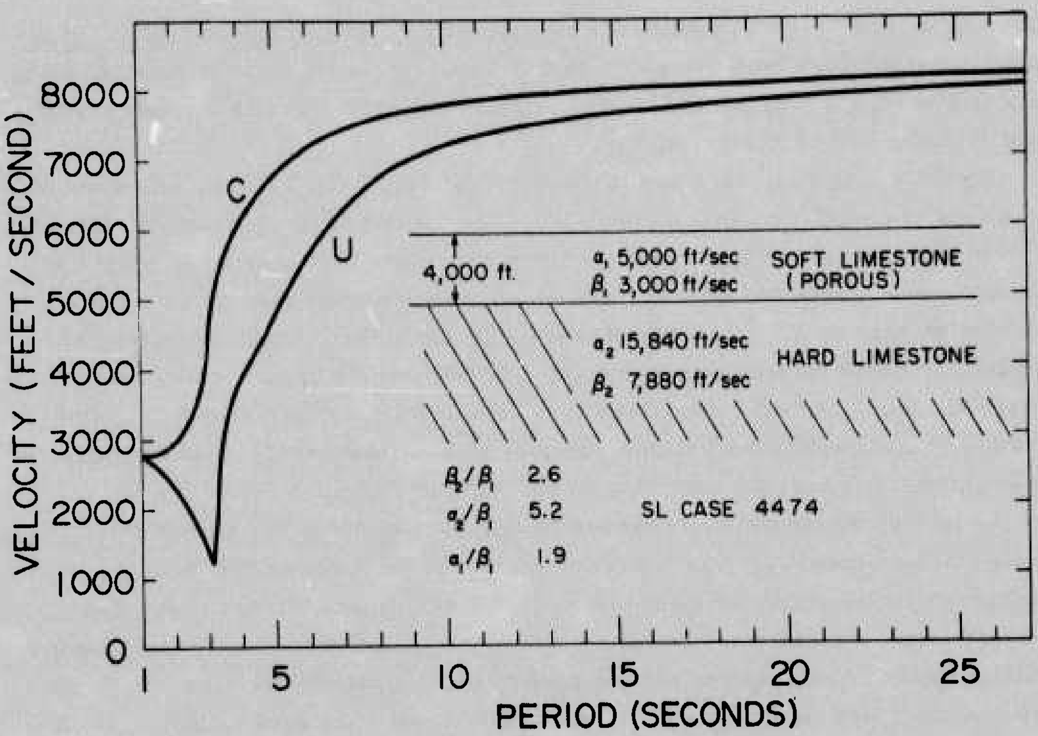

Figure 3. Predicted Rayleigh Wave Dispersion

source-receiver distance. Therefore, the contribution of the fundamental Rayleigh wave to the seismic record would not be considerable if this model is valid for the area.

6. SEISMIC ACTIVITY MONITOR (SAM)

The data acquisition instrumentation employed in the Richmond study was fabricated under Air Force contract specifically for the continuous monitoring of strong motion seismic activity.[13] Although specifically designed to collect seismic data, the design is such that it can be used for a broad range of applications by modifying the amplifiers for the intended usage. The SAM system is a self-contained automatic digital system whereby the most recent collected data are held in temporary storage and are continuously updated with time. Whenever the magnitude of the activity exceeds a threshold level, the SAM system is activated to record the data held in temporary storage on magnetic tape together

13. Kuenzler, H. et al, (1975) Modification and Additions to the Geokinetic Data Acquisition System. AFCRL-TR-75-0434.

with a quantity of post-threshold data regulated by a preselected time limit. The data stream includes both seismic data and time. Up to sixteen channels of analog data can be accepted by the SAM system in this manner. For the Richmond study SAM is short-cycled to six channels.

The SAM electronic memory is composed of 512, 6-bit bytes in which two of the 6-bits are used for identification purposes. Each A/D conversion consists of 12-bits that are written as three 4-bit bytes where one byte is written every four microseconds. Data and time are written once each second into the data stream in order of 100's, 10's, and units of days; 10's and units of hours, minutes, and seconds. Timing pulses are provided by a 400-kHz clock in combination with a series of control and scan rate dividers. Data is formated and transferred into temporary storage in the electronic memory of a modified model 1708 Kennedy tape recorder via the data control and data register cards.

As stated, the amplifier cards are so designed as befits the kind of data activity to be monitored. Per the requirements of the Richmond objectives, seismic amplifier cards, designed to accept signals from Geo-Space HS-10-1 seismometers, condition the seismic signals to produce two outputs, one proportional to ground displacement and one proportional to ground velocity. An Event Detector monitors these signals. If one or more amplifier card outputs exceeds a predetermined threshold level, an event pulse is generated. This pulse increments an Event Counter which in turn triggers the transient Mode Converter that controls the recording into permanent storage. The number of data records selected for recording is preset beginning with those records contained in temporary storage immediately preceding the triggered event pulse.

An extra amplifier card slot is available in the system for special purpose electronics. For Richmond, two channels of tiltmeter amplifiers are installed to provide signal conditioning for driving an external strip chart recorder where two channels of analog tilt data are recorded. The SAM system, as configured for the Richmond study, is depicted in Figure 4.

7. SENSOR DESCRIPTION

The SAM component sensor section, as configured for the Richmond study, consists of two sensor types with related amplifier electronics, namely the HS-10-1 Hall-Sears seismometer and the Talyvel Electronic Level (tiltmeter). The HS-10-1 seismometers are a 1-Hz velocity geophone having a coil resistance of 50 kΩ. They are 70% damped permitting a sensitivity of 22 V/in./sec. The seismic amplifier has three functional stages, the first stage having a gain of 1/4 followed by a unity gain low filter stage as the second stage. The third stage is an

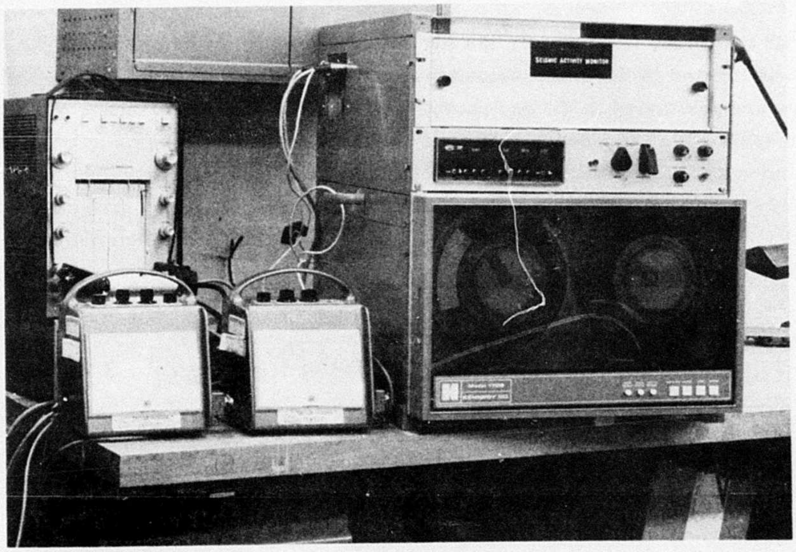

Figure 4. SAM System

integrator with a gain of 40 dB and a 16 dB/octive roll off beginning at 0.1 Hz. Its output is proportional to ground displacement. The velocity and displacement outputs are inverted relative to each other. The precise output polarities are a function of the seismometers. Sensitivity then through the amplifier is 5.5 V/in./sec at 1Hz. For frequencies above 1.0 Hz the displacement output is flat with a sensitivity of 183 V/in. while the velocity output above 1 Hz has a sensitivity of 6.60 V/in./sec.[13]

The Talyvel tiltmeter is an electronic bubble level in which the usual bubble is replaced by a pendulum operating in conjunction with a pair of inductance transducers. This combination provides an electrical displacement signal. The SAM tiltmeter amplifier accepts a differential output signal from the Talyvel amplifier circuitry. The input to the SAM tiltmeter amplifier is a unity gain differential in the first stage while the second and final stage has a gain of 40 dB and is low passed at 0.16 Hz. With the Talyvel set on the 8-min scale (three scales - 8 min, 100 sec, and 25 sec), the amplifier gain is ±200 arc sec which is equivalent to a ±10-V output. Sensitivity adjustment can be made by trimming the Talyvel gain control so that a 10-V reading on the associated analog recorder is equivalent to the tiltmeter off level by 200 arc sec.[13]

8. SENSOR-RECORDER LOCATION

With reference to Figure 1, the tilt and seismic recording portion of the SAM system is located in the Communication-Electronics Building (Bldg 070). Tilt sensors are positioned in the equipment bay of the Height-Finder tower No. 0, located some 400 ft southwest of Bldg 070. These tiltmeters are cable coupled to SAM channel 1. The seismic station is located approximately 150 ft north of Bldg 070 directly in front of the FAA Bldg at the elbow of the underground cable conduit joining the FAA Bldg to Bldg 070. The three HS-10-1 seismometers, monitoring the three components of earth motion, are approximately one foot below the surface, covered, and they are positioned such that seismic channel 1 (SAM channel 2) is the vertical motion sensor, seismic channel 2 (SAM channel 3) is the horizontal N-S motion sensor, and seismic channel 3 (SAM channel 4) is the E-W horizontal motion sensor. Sensor polarity is such that motions in the direction up, north, and east are positive in displacement. All sensor to recorder connecting cables are within the aforementioned underground conduits delineated in Figure 1.

9. SAM RECORDING GUIDELINES – RICHMOND STUDY

Guidelines for the routine operation of the SAM system at the Richmond site were established after reduction of the first set of collected data. Triggering threshold levels for both velocity and displacement were originally set too high, based on the frequency content of the explosion levels recorded during the first week of operation. The displacement threshold was reduced to 6% of the Dade County Explosive Code limits and the velocity threshold to 14%. Calibration of the seismic portion of the SAM system is made during every tape change interim. At this point a calibration time interval of 30-sec duration is alloted to each seismic sensor. The first calibration sequence for each seismometer is made on paper record, adjusting to 200 mV per minor division for displacement and 50 mV per minor division for velocity at a chart speed of 1 mm/sec. Calibrations are also made at the start of each new tape reel and at the termination of tape reel recording with the exception of a tape change due to power outages or equipment malfunction in which case no terminal calibrations are made. Under normal operational conditions, tape changes are made if the event recorder registers 10 events or if, after 30 days, less than 10 events are indicated. The usual tape layout then consists of a series of time-spaced data in the form of "files", the first two files being the calibration on/off sequence followed by the event files, that is, blast or other system triggering sources, and finally terminating again with the calibration on/off sequence representing the last two data files for that particular tape. Again, this format is used when the SAM system operation has not been interrupted by a power outage or equipment malfunction.

The record length of each tape file is selectable. The file time duration is a function of the scan rate and number of data channels. In the case of the Richmond Study, six seismic data channels are used (3 displacement, 3 velocity) and a scan rate of 100 scans/sec was selected. Using these parameters the file time length is 8.32 sec. Once the record length and scan rate are selected, the compositional format for each tape file is fixed. This format, as representative of each data tape acquired during the course of the Richmond study, beginning with the most basic unit, that is, the bit, is as follows:

4 bits	1 byte
3 bytes	1 word
512 words	1 record
32 records	1 file
1 file	8.32-sec duration

10. SEISMOMETER MOTOR CONSTANT CALIBRATIONS

Motor constant determinations on three Geo-Space HS-10-1 seismometers were made. Each seismometer is coupled to a SAM seismic channel. Prior to the calibration tests, the system bridge circuitry, for each seismic channel, was balanced together with determinations of each seismometer's coil resistance and natural frequency.

The calibration technique employed was the mechanical weight lift – electrical simulation comparison method. With the SAM system in the calibration mode, a small test weight is applied directly to the seismometer mass, and after allowing the mass to reach equilibrium, quickly removing the test weight; the resulting voltage output is measured at the displacement terminal of the respective channel via a retained signal on a storage oscilloscope. The displayed signal can be electronically simulated by interrupting a power source voltage applied to the calibration input terminals of the SAM system. By varying the applied voltage after each voltage source interruption, the original mechanical weight lift waveform can be duplicated in both amplitude and polarity. Knowledge of the weight removed and the current across the seismometer terminals generated to duplicate the mechanical weight lift provides sufficient information for determining the seismometers' motor constants in units of newtons per ampere, $G = Wg/I$. Using the manufacturer's specifications, the HS-10-1 sensitivity is 26 V/in./sec, which in terms of the motor constant equates to 1022 N/A.

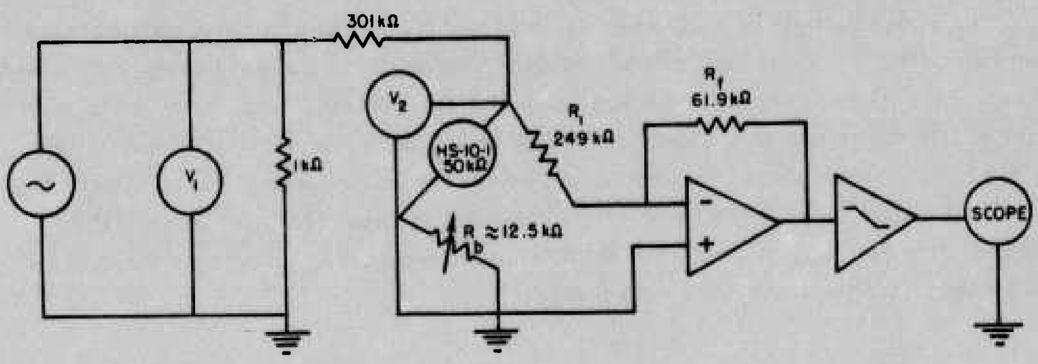

Figure 5. Calibration Circuitry

Table 1. Measured Seismometer Parameters

Dedicated Channel No.	Seismometer Component	Serial Number	Coil Resistance*	Natural Frequency**
2	HS-10-1 Z	42735	51.2kΩ	1 Hz
3	HS-10-1 H	66815	51.3kΩ	1.2 Hz
4	HS-10-1 H	66813	51.0kΩ	1.5 Hz

*The coil resistance was measured using a Tektronix scope Model 7704.

**The natural frequency was determined via Lissajous figures.

A special jig was used to perform the weight lift on the horizontal seismometers. The test weight is thread supported between the seismometer and the jig. The thread angle is then set between the test weight normal-seismometer and the test weight normal-jig to 45° each. Again the seismometer mass is allowed to reach equilibrium. The procedure now is the same as with the vertical seismometer commencing with the sudden removal of the test weight. Because of the geometry of this procedure, only one half the weight value of the test weight is used in the computations.

Table 2. Motor Constant Determinations

(A) HS-10-1 (Z) No. 42735 dedicated to SAM channel 2			
	1st test	2nd test	3rd test
Measured values			
Weight lift voltage (p-p)	-2.4 V	-2.7 V	-2.3 V
Electrical voltage (p-p)	-2.4 V	-2.7 V	-2.3 V
Weight lift time duration	4 sec	4 sec	4 sec
Electrical time duration	4 sec	4 sec	4 sec
V_1	-7.02 V	-6.55 V	-7.32 V
V_2	-0.849 V	-0.792 V	-0.884V
Constant values			
W	2×10^{-3}kg	2×10^{-3}kg	2×10^{-3}kg
g	9.80 m/sec^2	9.80m/sec^2	9.80 m/sec^2
Computed values			
ω_o	6.28 rad	6.28 rad	6.28 rad
I_1	16.6×10^{-6}A	15.5×10^{-6}A	17.3×10^{-6}A
G	1180 N/A	1265 N/A	1135 N/A

(B) HS-10-1 (H) No. 66815 dedicated to SAM Channel 3	
Measured values	
Weight lift voltage (p-p)	+0.9 V
Electrical voltage (p-p)	+0.9 V
Weight lift time duration	4 sec
Weight lift time duration	4 sec
V_1	+3.91 V
V_2	+0.472 V
Constant values	
W	2×10^{-3} kg (equivalent to 1×10^{-3}g)
g	9.80 m/sec^2
Computed values	
ω_o	7.44 rad
I_1	9.20×10^{-6} A
G	1065 N/A

Table 2. Motor Constant Determinations (Contd)

(C) HS-10-1 (H) No. 66813 dedicated to SAM channel 4	
Measured values	
Weight lift voltage (p-p)	+0.8 V
Electrical voltage (p-p)	+0.8 V
Weight lift time duration	4 sec
Electrical time duration	4 sec
V_1	+3.77 V
V_2	+0.455 V
Constant values	
W	2×10^{-3} kg (equivalent to 1×10^{-3} g)
g	9.80 m/sec^2
Computed values	
ω_o	9.42 rad
I_1	9.55×10^{-6} A
G	1041 N/A

Alternate Method

An alternate method for determining the motor constant of the vertical seismometer was employed. This method is based on establishing the spring constant. This is accomplished by measuring the actual displacement of the seismometer mass by adding a known test mass to the seismometer mass. The spring constant is computed from the test mass - displacement proportion times a gravitational constant.

$$k = W_g/X_1.$$

The motor constant can then be found as the product of the spring constant and the mass displacement, measured through some arbitrary distance, divided by the current change needed to accomplish this displacement measured across the seismometer terminals.

$$G = kX_2/\Delta i.$$

Table 3. Motor Constant Determined by Alternate Method

HS-10-1 (Z) No. 42735	
Measured values	
X_1	222×10^{-4} cm
X_2	200×10^{-4} cm
V_1	-6.55 V (pre mass displacement)
V_1	-10.49 V (post mass displacement)
V_2	-0.79 V (pre mass displacement)
V_2	-1.27 V (post mass displacement)
Constant values	
W	1 gm
g	980 cm/sec^2
Computed values	
k	44,500 dynes/cm (0.445 N/A)
Δi	8.9×10^{-6} A
G	1000 N/A

Symbols

f_o	Natural frequency,
g	Gravitational acceleration constant,
G	Motor constant,
I_1	Seismometer current - electrical weight lift simulation,
Δi	Current change for arbitrary seismometer mass displacement,
k	Spring constant,
V_1	Power source voltage across calibration terminals,
V_2	Seismometer output voltage,
X_1	Displacement of seismometer mass due to added weight,
X_2	Displacement of seismometer mass due to applied current,
W	Mass,
ω_o	$2\pi f_o$.

References

1. Lt Col Oaks, M., Ltr 6 Dec 1971, Subject: Blast Damage to Government Property.
2. EN-DI Disposition Form, 3 March 1972, Subject: Blasting Effects at Richmond Air Force Station, Florida.
3. Dade County Code on Explosives (1973), Dade County, Florida.
4. Minutes of ADC Meeting Concerning Sterling Stone Crushing Co, 17 Dec 1971.
5. Keith, J., Ltr 11 Feb 1972, Subject: Consultation Concerning Blasting Effects at Richmond Air Force Station, Florida.
6. Harris, C., and Creed, C. (1961) Shock and Vibration Handbook, Vol 3, McGraw-Hill Co., New York.
7. Parker, G., and Cook, W. (1944) Late Cenozoic Geology of Southern Florida with a Discussion of the Ground Water, Geological Bull. No. 27, Florida Geological Survey.
8. Cook, W., (1945) Geology of Florida, Geological Bull. No. 29, Florida Geological Survey.
9. Puri, H., and Vernon, R. (1964) Summary of the Geology of Florida and a Guidebook to the Classic Exposures, Special Publication No. 5, Florida Geological Survey.
10. Clark, S. (1966) Handbook of Physical Constants, Geological Society of America, New York.
11. Mooney, H., and Bolt, B. (1965) Dispersion Tables for Rayleigh Waves on a Single Surface Layer, VESIAC Special Report 4410-102-X.
12. Ewing, W., Jardetzky, W., and Press, F. (1957) Elastic Waves in a Layered Media, McGraw-Hill Co., New York.
13. Kuenzler, H. et al. (1975) Modification and Additions to the Geokinetic Data Acquisition System, AFCRL-TR-75-0434.

Appendix A

SAM Operational Procedures

A1. SYSTEM SETUP

(a) Place SAM in desired location and connect AC power cord. Fan and digital clock will turn on when 120 VAC, 60 cycle power is applied.

(b) Set Clock. Put the SET/RUN switch in the "SET" position. Depress and hold the set push buttons until the desired date and time are displayed. Put SET/RUN switch into the "RUN" position.

(c) Set SAM'S MODE switch to "STANDBY."

(d) Connect seismometer cables to the appropriate input connectors on SAM'S terminal panel.

(e) Connect tiltmeter's cables to the appropriate input connectors on SAM's terminal panel.

(f) Connect the Gould recorder cable to the "RECORDER" output connector on SAM's terminal panel.

(g) Connect the Gould recorder cable to the Gould recorder analog inputs.

(h) Connect the event marker output to the center marker pen of the Gould recorder (rear of cabinet).

(i) Connect Gould AC power cable to suitable outlet.

(j) Set up Talyval Tiltmeters.

A2. RECORDER PREPARATION

(a) Load new reel of magnetic tape on the Kennedy 1708 Recorder in accordance with instructions in the Kennedy manual. Be sure the write ring is installed on the new reel.

(b) Turn on Kennedy power switch (located in lower left corner of Kennedy console, inside hinged door). "WRITE ENABLE" light should turn on if a write ring is installed.

(c) Press "LOAD" button. Tape will advance to the load point and stop.

(d) The "Transient Mode Converter" (TMC) card is physically mounted to the back plate of the Kennedy electronics card cage. Check to be sure that the mode switch on this card is set to "TRANS" and that the record counter selector switch (8-position DIP switch) has been set to the number of records to be recorded after the arrival of a transient. The switches are numbered in binary sequence in ascending order, that is, 1, 2, 4, 8, 16, 32, 64, 128 for switch positions 1, 2, 3, 4, 5, 6, 7, 8 respectively. The number of records to be taken is selected by switching to the "ON" position each switch of the appropriate weight. For example, 44 records will be taken if switch positions Nos. 6, 4, and 3 are pushed to the "ON" position (32 + 8 + 4 = 44). Note: Only even numbers can be set as switch position No. 1 is internally held at zero.

(e) Press the "ON LINE" push button to enable the Kennedy to accept data.

A3. SYSTEM PREPARATION

(a) Place TEST/RUN switch in slot (A7) (SCAN CONTROL CARD) in the TEST position.

(b) Select the desired scan rate by switches S1 and S2 on the SCAN CONTROL CARD (A7) in accordance with the set matrix printed on the hinged door.

(c) Turn the ON/OFF power switch (located on the right-hand side of the panel with the calendar clock) to the ON position. This applies power to the remainder of the system.

(d) The EVENT DETECTOR CARD (A6) will display two random digits on the EVENT COUNTER. Depress the RESET button on (A6) to reset the counter to zero. Depress the LAMP TEST button on (A6) to test all segments of the LED display. During lamp test "88" will be displayed.

(e) Depress the "RESET" button on (A7). If it is desired to test any channel (from 0 to 5) and display the digitized data, set the CHANNEL SELECT switch on (A7) to the correct channel number and depress the "CONVERT" push button. The digitized data will appear on the LED display output of the DATEL A/D along with the selected channel number. If a number larger than 5 is selected, the data displayed will be invalid since the unit is short cycled to accept only six channels, (that is, 0 through 5).

(f) Push the TEST/RUN switch in slot (A7) to the "RUN" position. The DATEL A/D will now convert data at the selected scan rate. Data will be formatted and transferred to the Kennedy internal memory. The Kennedy will not write data onto magnetic tape until the arrival of an event.

(g) Test the Kennedy transient record mode by depressing the "EVENT" push button. When depressed, the Kennedy will start recording and will write off the selected number of records before again becoming inactive awaiting another event. (Note: the EVENT push button serves only to trigger the Kennedy. It will not increment the EVENT COUNTER.) Test the entire system transient detection operation by striking the ground or a seismometer directly to produce a signal large enough to qualify as a bona fide seismic event. This test should cause the EVENT COUNTER to increment and the Kennedy to write the predetermined number of records. (Note: seismic events which occur during the same 16-sec period of time are counted as being a part of the first event to trigger the recording system. After the expiration of the 16-sec timer, another arrival will be counted as a separate event). A convenient method of simulating an event is by applying an external calibration signal via the red and black SEIS. CAL inputs on the terminal panel, the CALIBRATE toggle switch on the SAM's front panel, or applying an internal calibration input via the CALIBRATE and INTERNAL toggle switches on the front panel.

Adjustment to eliminate common mode signals at the amplifier may be made by means of the 10kΩ potentiometer R4 in the non-inverting input of the first amplifier. If common mode adjustment is required, the seismometer should be locked and a calibration signal applied. Adjust the 10kΩ potentiometer to give minimum output at the orange test point. Test points at the rear of each seismic amplifier card are defined as follows:

(1) orange - pre-amp output,
(2) yellow - velocity output,
(3) green - displacement output,
(4) black - ground.

If it is desired to observe seismometer signals on oscilloscope or strip chart, these signals are available at the test points above.

Calibration current is supplied to each seismometer via front panel switches. An internal calibration of 10.0 V is furnished. External calibration inputs are available. The calibration constant is 2.35 μA/V.[13]

UNCLASSIFIED

AD B008881

AUTHORITY: AFGL

ltr 6 Nov 81

UNCLASSIFIED